Design and Development of Cost-Effective Solar Rechargeable Led Lantern

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Abstract:- In many countries of sub-Saharan Africa including Nigeria, more than 70% of the people live in off-grid communities where they depend on kerosene hurricane lanterns and candles to light their homes and batteries for their torches and radios. Battery charging using portable generating set is an increasingly common service in these communities. The fume from the generating sets and from burning kerosene and candle is toxic and lead to respiratory illnesses over time. For most people in this setting, their living conditions could be improved simply by providing cost effective renewable energy power sources that would power LED lamps, radio sets and other electronic appliances. It is the goal of this project to develop affordable solar lantern kit for use in rural households in Nigeria. The solar lantern kit consists of an 8-W solar panel, 2 light sources consisting of high efficiency LED lamp capable of producing 6-hours of light of ≥ 800 lumen each, and a charge control circuit capable of fully charging 2 rechargeable 3.7V lithium-ion batteries in 6 hours of direct sunlight using the external 8-W solar panel.

Keywords:- *Rechargeable Lamptern; Solar; LED; Styling; Insert.*

I. INTRODUCTION

In many countries of sub-Saharan Africa, more than 70% of the people are off grid. The situation is even worst for rural areas where about 95% of the populace are without electrical power supply. Largely, the people depend on kerosene and candles for lighting, and batteries for small appliances [1]. For instance, in a country like Nigeria, more than 120 million people are without access to electricity, consequently leading to the use of costly and even harmful energy sources [2].

Successive World Bank surveys have always shown the prospects for decentralized power supplies for lighting, both at community and household level in these countries [1]. These studies showed that solar rechargeable lanterns are an affordable, environmentally-friendly, and portable lighting option for large sections of the rural communities in these countries. However, despite the growing interest in solar lantern, available products in Nigerian market are imported and highlighted a number of technical shortcomings. The shortfalls often highlighted include inferior construction of the lighting fixture, poor illuminance, and the relatively poor performance of the fixture after being used for a short period. In many instances, users of the solar lanterns end up discarding them after few months of usage because they lack access to affordable spare parts.

Based on the results of technical analysis of selected solar rechargeable lanterns and general discussions with users, some important features were considered and they include:

- Lantern should provide white light equivalent to the output of a 15 Watt CFL for up to 6 hours every day
- The lighting fixture should be able to cover a 360 degree spread of light
- The lighting fixture will be portable with a good base
- The lighting fixture shield should will be translucent with minimum dispersion effects
- The fixture will also have a charging indicator to indicate charging, and under-discharge light to indicate that the battery is low.
- An auxiliary socket for powering small electronic devices with minimal power rating.

II. DESIGN PARAMETERS

It is the aim of this research to develop a solar rechargeable lantern kit capable of producing 6-hours of light of ≥800 lumen, and a charge control circuit capable of fully charging 2 rechargeable 3.7V lithium-ion batteries in 6 hours of direct sunlight using 8-W solar panel.

Table 1: Design parameters for the proposed Solar rechargeable lamp

Characteristic	Value
Light Output	15 Watt CFL
Battery Duration	6hours
Intensity	≥ 800 *lumen*
PV panel rating	8W
An auxiliary power outlet	5V/1.5A(I_L)

The major goal of this project is to develop an improved and cost-effective solar rechargeable LED-based lantern as an alternative solution for kerosene lamps. This demands developing specific characteristics to exceed that of those available in the market. The proposed solar lighting fixture consists of a PV module, which provides solar energy; a rechargable Lithium Ion battery for storing energy; a charge controller to control charging rate of the battery so as to prevent over-charging; auxiliary supply socket to power small appliances; LED's and the LED driver.

III. DESIGN FLOW

The design flow process of all the segments of this research is as shown in the block diagrams below:

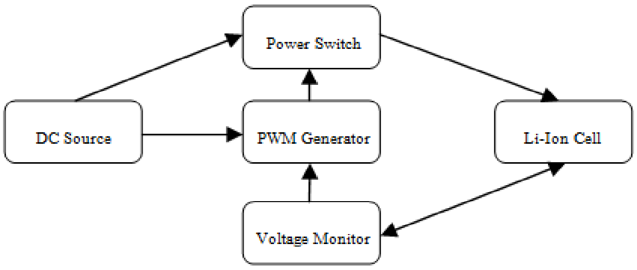

Figure 2: Block Diagram of the entire process

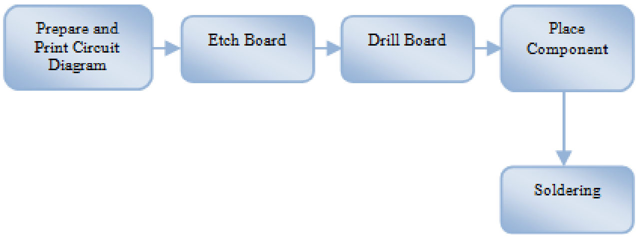

Figure 3: Design process of Circuit board

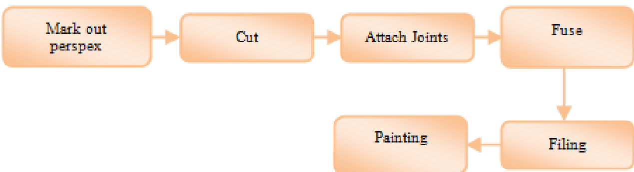

Figure 4: Design process of Casein

Figure 5: Design process of Diffuser

Figure 6: Complete Design process

IV. SYSTEM DESCRIPTION

The Li ion charger designed for this system is a voltage-limiting device and is similar to the charging system of a lead acid. They are some differences between the two systems; Li-ion has a higher voltage per cell, alongside a tighter voltage tolerances. Li-ion cells are designed in such a way that they follow the correct settings placed by the manufacturers, because Li-ion cannot accept overcharge. Charging a Li-ion battery consists of three stages: pre-charging stage (slow charging), constant current charge (fast charge) and constant voltage charging stage [3]. Figure 7 shows a plot of the current vs voltage curve of the Li-ion battery.

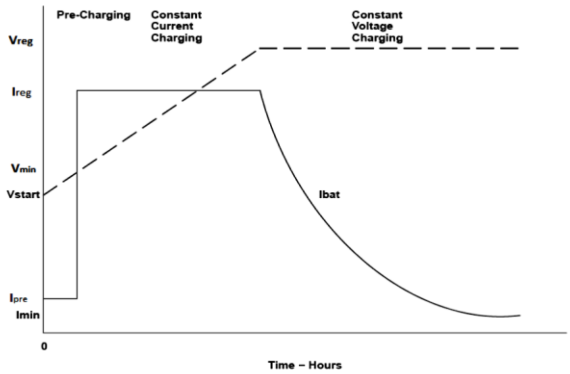

Figure 3: Current vs Voltage curve of Li-ion battery [3]

The block diagram of the Pulse Width Modulated (PWM) charge controller is shown in Figure 2. The DC source (an 8 watts PV panel) provides power to charge the Li-ion cell, as well as power the PWM generator circuit. The power switch is a power transistor switched by the high frequency PWM pulses from the PWM Generator. The Voltage Monitor monitors the terminal voltage of the Li-Ion cell, when the terminal voltage gets to 4.2V (Full Charge voltage of the Li-Ion cell), it sends a short-off signal to the PWM generator, stopping the charging process. The flow of electricity is regulated by the charge controller as power flows from the PV modules to the battery and the load. The charge controller prevents the battery from being over charged after being fully charged. During the charging process, as soon as the controller senses that the battery is fully charged, it will stop the flow of charge from the modules.

The charge controller is based on TL494, it houses in a single chip, most of the features required to construct of a pulse-width modulation (PWM) control circuit. It contains two error amplifiers, an adjustable oscillator embedded on the chip, a dead-time control (DTC) comparator, a pulse-steering control flip-flop, a 5-V, 5%-precision regulator, and output-control circuits [4].

During operation, the oscillator helps to provide a positive saw tooth waveform to both the dead-time and PWM comparators to enable comparison of the various control signals. To program the frequency of the oscillator, the timing components RT and CT are altered. The external timing capacitor (CT) is charged by the oscillator with a constant current. This value is determined by the external timing resistor, RT. This produces a linear-ramp voltage waveform. When the voltage across CT reaches 3 V, the oscillator circuit discharges it, and the charging cycle is reinitiated.

To enable modulation control of the output pulse, the comparator is employed. To achieve this, the control signal at the error amplifiers is compared to the ramp voltage across the timing capacitor CT. A diode is connected in series with the timing capacitor and it is usually omitted from the control signal input. When the error amplifier output signal is approximately 0.7 V greater than the voltage across CT, it will inhibit the output logic. This connection helps to ensure that the it gets to maximum duty cycle operation without requiring the control voltage to sink to a true ground potential [4]. As the voltage of the error amplifier output varies from 0.5 V to 3.5 V, the output pulse width varies from 97% of the period to 0 respectively. The circuit diagram of the system is as shown in figure 8:

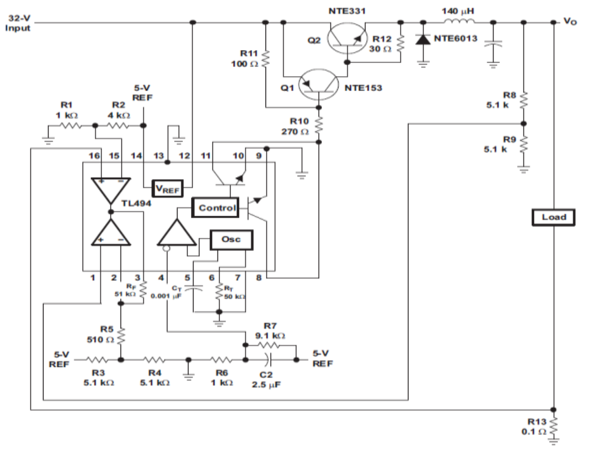

Figure 8: Circuit diagram of the TL494 circuitry

The power supply range of the TL494 is between 7 V and 40 V which is usually regulated properly [4]. A bulk capacitance alongside a ceramic bypass capacitor is required to be added to the circuit if the power supply is located some inches away from the device. In this design, a 47 µF tantalum capacitor was used. A low EMI inductor with a ferrite type closed core was used. Since the ceramic input filter capacitor has a low value, it was located very close to the VCC pin of the IC. This helps to reduce the inductance effects to as much lower value as possible. This provides a cleaner voltage supply to the internal IC rail.

To determine the size of the inductor (L), the following calculation was done:

d = duty cycle = V_O/V_I = 5 V/32 V = 0.156
f = 20 kHz (design objective)
t_{on} = time on (S1 closed) = $(1/f) \times d$ = 7.8 µs
t_{off} = time off (S1 open) = $(1/f) - ton$ = 42.2 µs
$L \not\approx (V_I - V_O) \times t_{on}/\Delta I_L$
$\not\approx [(32\text{ V} - 5\text{ V}) \times 7.8\text{ µs}]/1.5\text{ A}$
$\not\approx 140.4\text{ µH}$

After calculating the value of the filter inductor, the value of the output filter capacitor is selected to match the requirement of the output ripple.

The design also monitors the battery temperature of the device using an NTC (Negative Temperature Co-efficient) thermistor. To monitor the temperature, a 10kΩ, B = 3380 NTC thermistor is connected from the NTC pin to ground. This pin monitors the voltage dropped across the 10kΩ thermistor and sources about 50µA. During operation, when the voltage on the NTC pin is above 1.36V (0°C) or below 0.29V (40°C), the temperature of the battery is considered to be out of range. When this happens, the circuit will indicate an NTC fault. The triggered fault condition would remain except the voltage on the NTC pin falls within the range of 0°C to 40°C [5].

The circuit printed circuit board is as shown in figure 9.

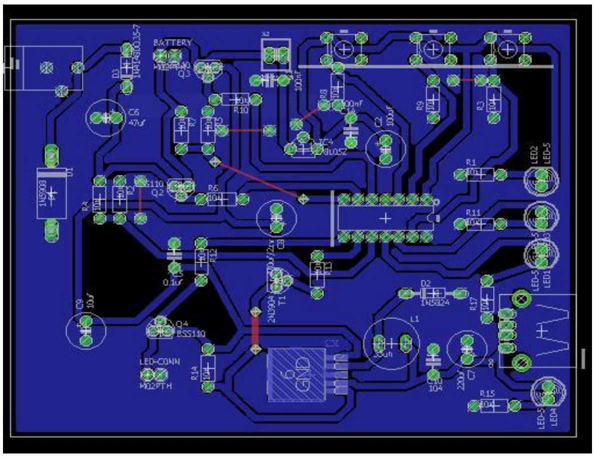

Figure 9: Circuit PCB

V. CONCLUSION

In this paper, a solar powered lantern kit consisting of an 8-W solar panel with 2 rechargeable 3.7V lithium-ion batteries and LED luminaires has been designed. The system is capable of producing a luminance value greater than or equal to 800 lumens. The charge controller unit circuit designed is capable of fully charging 2 rechargeable 3.7V lithium-ion batteries in 6 hours of direct sunlight using the external 8-W solar panel.

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